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LETTER TO THE EDITOR

Surface residual stresses of LSM-treated martensitic stainless steel

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Abstract. This is an investigation into the effects of laser surface melting (LSM) on martensitic stainless steel, commonly used for steam turbine blades. The principal result is that the magnitude of overlap between neighbouring melted tracks determines whether or not the surface residual stress is tensile.

Martensitic stainless steel is extensively used for steam turbine blades, which are continuously subjected to erosion by water droplets. Laser surface melting (LSM) treatment, which will result in homogeneous surface layer structures, is undoubtedly favourable to the service properties of the blades. Therefore, the properties and structure characteristics for steel with LSM treatment have been investigated [1, 2]. The surface residual stress, however, has not been studied in detail.

Generally speaking, LSM of martensitic stainless steel results in surface residual compressive stress in single tracks, and becomes tensile if multi-pass scanning is employed, with overlapping between two neighbouring tracks [3, 4]. Naturally, surface tensile stress is unfavourable to the fatigue strength and should be avoided. However, our experiments indicate that multi-pass LSM scanning with overlapping zones does not always result in surface tensile stresses for martensitic stainless steel. The sign of residual stress depends on the size of the overlapping zone. When the overlapping zone is large enough with respect to the size of melting pool, the surface residual compressive stress becomes significant and the opposite is true if there exists a small overlapping zone.

Table 1 shows the composition of the chosen martensitic stainless steel, which was subjected to hardening (1050 °C, 0.5 h, cooling in air) and tempering (720 °C, 10 h), followed by machining into the sample ($10 \times 15 \times 70$ mm^3). The samples were laser surface melted by multi-pass scanning over the whole surface (15×70 mm^2).

Two laser treatment conditions resulting in small and large overlapping zones were employed for the consideration of two extreme cases, as shown in table 2.

The residual stress profile and average stress were measured for the surface layer of the samples treated by LSM according to the method mentioned in [5]. The surface structure was examined by means of an x-ray diffractometer (Mo Kα = 0.71069 Å). The corresponding specimen was 0.1 mm in thickness (less than the thickness of the melted layer), obtained by cutting the laser-treated layer parallel to the treated surface.

Figure 1 indicates the profiles of residual stress parallel to the surface and tracks for two samples, whose surface average residual stresses perpendicular to and parallel to the tracks are shown in figure 2. We know that for sample 2, there is a tensile stress profile

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Table 1. Composition of martensitic stainless steel.

Element	C	Cr	Mo	V	Ni	Si	Mn	Fe
Content (wt%)	0.22	12	1.0	0.3	0.7	0.2	0.7	rest

Table 2. Laser surface melting treatment parameters.

Sample	Power	Scan velocity	Distance from focus	Pass step
1	1.5 kW	2 m min^{-1}	−10 mm	0.72 mm
2	1.5 kW	30 m min^{-1}	0.0	0.23 mm

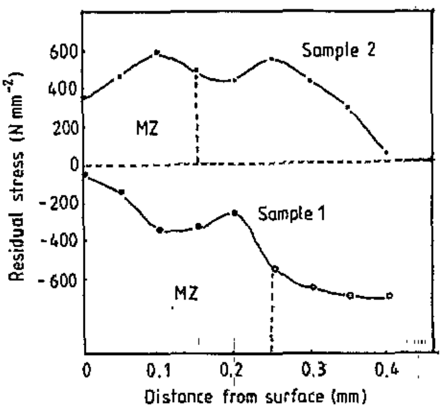

Figure 1. Profile of stress (parallel to track). MZ is the melting zone (—○—, sample 1; —●—, sample 2).

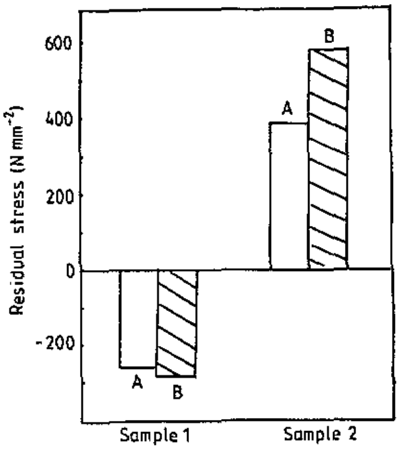

Figure 2. Average residual stresses in the surface layer: A, perpendicular to track and B, parallel to track.

and an average stress that we usually anticipate. But for sample 1, there is a compressive stress which is favourable to fatigue resistance; this is significantly different from earlier works [3,4]. X-ray diffraction of surface layers shows that the structures in the melted zone consist of about 8% martensite and retained austenite. Figure 3 is the corresponding diffracted spectral line. The effect of so small an amount of retained austenite on residual stresses can be ignored. So the surface layer residual compressive stresses in sample 1 do not result from the existence of the retained austenite.

The measurements of the melted zone size for two samples (see table 3) indicate that with respect to the size of melting pool, the overlapping zone between the two neighbouring melted tracks for sample 1 is much larger than that for sample 2.

Table 3. Sizes of the melted zones. *a* is the surface width of the melting pool; *b* is the overlapping width between two neighbouring tracks at the surface; *c* is the depth of the melting pool and *d* is the thickness of the heat-affected zone. All quantities are illustrated in figure 4.

Sample	*a*	*b*	*c*	*d*
1	1.5 mm	0.78 mm	0.25 mm	0.35 mm
2	0.34 mm	0.11 mm	0.15 mm	0.10 mm

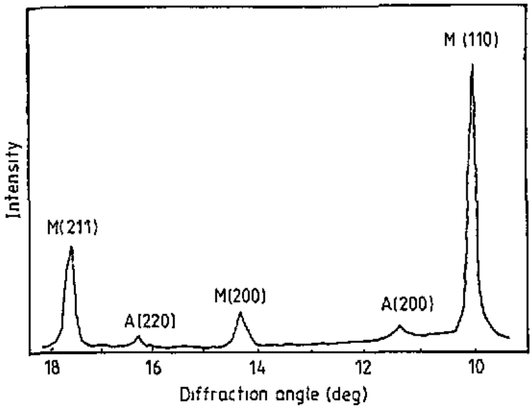

Figure 3. XRD pattern of the melted layer.

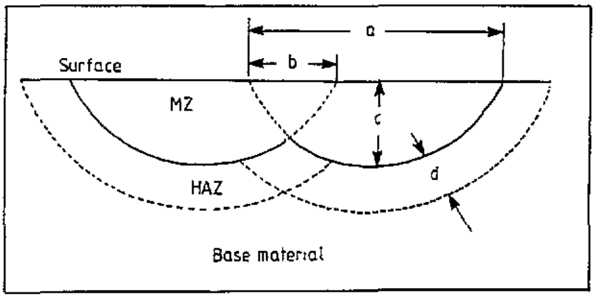

Figure 4. Schematic diagram for the laser-treated layer. MZ is the melted zone; HAZ is the heat-affected zone; *a*, surface width of melting pool; *b*, surface overlapping width; *c*, depth of melting pool and, *d*, thickness of HAZ.

In addition, the thickness of the heat-affected zone for sample 1 is also much larger. Based on these data, we know that, for multipass scanning with overlapping, whether the residual stresses are tensile or compressive depends on the size of the melting pool, and especially the magnitude of the overlapping zone, because of the interactive effects between the neighbouring tracks, and melting pool and base material. It has been shown by further experiments and analysis [6] that generally when the overlapping width at the surface is more than half of the surface width of the melting pool, there will be significant compressive stress in the surface layer; when the overlapping zone is too small, usually there is tensile stress in the surface layer which should be avoided due to being unfavourable to the fatigue resistance.

For the martensitic stainless steel, the surface residual stress induced by multi-pass laser scanning with overlapping between the neighbouring melted tracks is not always tensile, depending mainly on the magnitude of the overlapping zone. A large overlapping zone is favourable to form surface residual compressive stresses; too small an overlapping zone usually results in tensile stresses as we anticipate.

The laser surface melting treatment in this work was performed at the Swiss Federal Laboratories for Materials Testing and Research (EMPA) in Switzerland.

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